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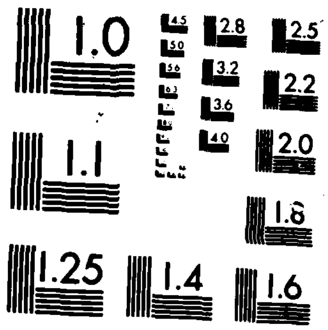

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A Survey of O&S Cost Models

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CONTENTS

I. INTRODUCTION

In September 1985, ~~ASC was~~ awarded ~~a contract~~ to develop procedures to estimate outyear operating and support (O&S) costs for new weapon system. These procedures to be develop were to differ from existing O&S cost models in sensitivity to design decisions and how design decisions impact O&S costs. As task I of this effort, ASC and its subcontractor Science Applications Incorporated (SAI) were to review existing methodologies for estimating operating and support (O&S) costs of weapon systems. This report documents the team's efforts to date.

Chapter 2 describes ~~our~~ approach to reviewing existing methodologies. It also summarizes ~~our~~ findings. Chapters 3 and 4 discuss the methodologies reviewed. Chapter 3 addresses Navy models while Chapter 4 discussed the other services models.

II. METHODOLOGY REVIEW

Background:

The Statement of Work for this study specifies the development of "macro procedures" for estimating the O&S portion of life-cycle costs of weapons systems. Use of these procedures ... "should start as early as concept formulation, and become refined and more accurate as the system progresses toward production." Current practice starts with cost relationships which rely heavily on analogy and Cost Estimating Relationships (CERs) and then introduces bottom up cost analysis as the program matures. The problem with this approach, as currently practiced, is that design and policy decisions made early in the program tend to lock in O&S costs before the detailed information needed for the bottom up approach is sufficiently developed. The bottom up cost analysis is used primarily to document decisions already made rather than as a tool to assess the impact of such decisions before the fact.

What is needed is an O&S cost model that incorporates consistency in methodology throughout the acquisition cycle. Such a model would start with what is essentially a bottom up approach applied to a Baseline Comparable System (BCS), extend this analysis to a new system, and refine the accuracy and comprehensiveness of the input data as the program matures.

To illustrate, one approach to estimating spares costs is to base them on

historical factors reflecting the flyaway investment cost of a similar system. This procedure provides a baseline which is an essential first step. However, the baseline may be related only in a very casual way to the system under consideration. Furthermore, such an estimate lacks continuity because refinement consists of abandoning the original estimate as concept development progresses rather than building on it. We believe that a feasible and better approach is to begin with an established causal relationship between identified cost drivers and initial spares cost applied to the baseline system. Refinement of the cost estimate then consists of first defining the estimated differences in qualitative and quantitative characteristics of the cost drivers between the baseline and proposed system. The same cost estimating relationships are then applied to the new system, but with more accurate or representative cost driver information.

For use in the early stages of a projects acquisition cycle (say before FSD), the type of model envisioned would still, by necessity, use analogy and cost estimating relationships. The difference between this model and current practice is that analogy and CERs are used to define the system rather than to determine costs directly. For instance, Reliability and Maintainability are important cost drivers in determining organizational, intermediate, and depot personnel requirements. However, the form and parameters of the cost estimating equations depend directly on numbers and repair level of removable assemblies. Personnel requirements can be estimated based on parameters such as the size and weight of the new system and assumptions about reliability compared of an analogous system, but this approach can lead to a deadend as the system evolves. A more desirable

approach is to estimate the reliability and repair times of individual weapon removable assemblies (WRA) and shop removable assemblies (SRA) using the analogous system as a baseline. Then as the design evolves, new data are substituted for WRAs and SRAs as they are refined, and new estimates made of manpower requirements. This provides continuity and consistency between the baseline and conceptual systems.

Approach:

The initial step in this effort was to identify existing O&S cost estimating methodologies (or models). This was accomplished by interviewing representatives from Navy cost organizations and reviewing cost analysis literature, particularly cost model documentation. Unlike the interviews, the literature review was not restricted to Navy work but examined Air Force and Army work as well.

The interviewees included representatives of the Navy Center for Cost Analysis, and the three cost groups in the Navy's System Commands (Air 524, Sea 017, and 82B). The interviews revealed that formal responsibility for O&S costing rests with the PMO, with the cost groups providing only limited support, usually in the form of individual members of these cost groups providing cost support to specific projects for O&S costs. Only the NAVAIR cost group (AIR 524) has a section devoted to support costing. These cost groups do not maintain nor have they sponsored the development of O&S cost models. Apparently, the lack of interest in cost model development reflects the project orientation of O&S costing in

Navy Systems Commands. Not having formal responsibility, the cost groups have not felt the need for devoting resources to O&S model and database development. At the same time, it is seldom worthwhile for an individual project to develop and implement an O&S cost model.[1]

Our literature search focused on 1) past reviews of existing cost estimating methodologies, particularly those done by RAND, LMI and Hardman and 2) detailed descriptions of existing cost estimating methodology. This review generated an extensive list of models that might apply to O&S costing. For purposes of this report, and for purposes of our project, it immediately became necessary to limit the number of models considered in detail. Reviewing all available material was neither practical nor feasible.

We limited ourselves in a variety of ways. First, we restricted ourselves by the kind of model we considered. Models can be divided into two broad categories - predictive and accounting. Predictive models take input data and via some kind of estimating procedure create output which was not input. Accounting models require all output data to be input. Accounting models perform two real services. One, they request information in a structured way; two, they add, sort, and assemble the data. To be useful, accounting models should be computer based to accomplish their primary goal of efficient data manipulation. (Of course, predictive models can be combined with accounting models by providing algorithms which can be used manually or with calculators.) We paid the most attention in our review to predictive models. Although where Navy accounting models exist and are well known, we reviewed them. We included all relevant

predictive models without regard to their methods for prediction, including parametric, simulation, and process models.

Second, we limited ourselves to O&S models that were formally documented and non-proprietary.[2] The purpose of our survey was to uncover models that could be used in our own development work. Undocumented and/or proprietary models are of no use. Third, we did not investigate models developed internally by hardware manufacturers and support contractors, that are not in the public domain. Three models that are widely used or well regarded are thus not included for that reason. These are PRICE, developed by RCA; Life Cycle Cost Analyzer (LCCA), developed by The Analytic Sciences Corporation; and the Total Resource and Cost Evaluator (TRACE), developed by Honeywell, Inc. On the other hand, we did not exclude models simply because they have remained dormant for a long time. For example, NAVMAN, a RAND model developed in 1979 which estimates maintenance personnel was reviewed because it was developed to be useful in the early stages of a projects acquisition cycle. Finally, we did not consider models developed for specific projects.

The criteria discussed above were essential and useful filters. However, the overriding requirement for selecting candidate O&S cost models is that their methodology allow them to be effective early in the design process when the majority of Life Cycle Costs are determined. Additionally, the cost model inputs must be obtainable from current data bases, and must be compatible with the established organizational responsibilities within the Navy Systems Commands. Current practice, for instance, fractionates cost analysis responsibility among

designers, logisticians and cost analysis groups. An effective cost analysis system must provide cost communication among system design groups, logistics specialists, cost analysis specialists and program management personnel. Because manpower costs are the largest single element in LCC, the model must cover relevant manpower, personnel, and training (MPT) costs and estimate them correctly. The model must also address system design, and integrated logistics support (ILS), and tie these together in such a way that the Program Manager can make timely and intelligent trade-off decisions. The model should also assist the PM in integrating the data used in developing the Logistics Support Analysis (LSA), TPM, ILSP, and Work Breakdown Structure (WBS).

Specific criteria that were used to identify and evaluate current cost models are:

- Can be used effectively early in the Weapons Acquisition cycle before O&S costs are locked in, and structured so that inputs can be refined as the program matures.
- Identifies implicit or explicit trade-offs between cost and performance or capability, and between acquisition cost and O&S costs.
- Uses cost elements that are internally consistent and responsive to the CAIG guidelines, and are defined in terms of Navy programming, budgeting and accounting categories.
- Compatible with existing Navy databases.
- Outputs in terms of absolute costs in order to be able to compare and trade off O&S and acquisition costs.

- Uses algorithms for resource categories that are responsive to a wide range of system characteristics, support concept and operations concept cost driver variables.

Findings:

Our findings from this survey are as follows. No comprehensive, predictive model for O&S costs has been developed and implemented for the Navy. Moreover, only a few models have been implemented for major subparts of O&S costs, and most of these models do not estimate O&S costs directly. These models include Tiger, Case and the Level of Repair Models (1390B models).

A variety of models exist for determining initial spares. Initial spares are a support investment item and therefore not directly germane to this study. However, it appears that the O&S item replenishment spares should be estimated by the same processes. This point needs further exploration.

We did find two comprehensive O&S models that were fully developed, but not implemented. Both of these had the same goals as our project, the development of a comprehensive (i.e. covers all O&S cost elements) cost model and structured for use in relating O&S costs to design decisions, particularly those made early in a project's life. One of these was developed by RAND for (Air Force) aircraft; the other was commissioned by the Navy's Hardman's project with an emphasis on avionics and electronics. These two fully articulated cost models came to our attention early enough to be reviewed in some detail. Because they are comprehensive

models that appear to be useful for our own development work, we reviewed them for that purpose. This review appears in the appendix to this report.

Our bibliography is intended to be a comprehensive listing of the models and reviews of models that we have found reference to. There is tremendous overlap in the models, not unexpectedly given the Air Force, Navy and Army all need to estimate O&S costs. We reviewed models whose documentation was available and which from a preliminary screen appear useful. While not every model has been thoroughly reviewed by the ASC/SAI team, we have reviewed each model sufficiently to determine that is has some use some for our further development.

We have thus satisfied the objective of our survey which is to identify and review those existing models and procedures which are compatible in purpose and which can relatively easily be integrated into the overall comprehensive model (or models) being envisioned here.

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[1] At least this is the Navy experience. Other researchers have noted that project specific models appear in the other services, particularly the Air Force. This may reflect the SPO concept.

[2] We did not review Life Cycle Cost models. Defense System Management College (DSMC) had commissioned a survey of such models in 1984. None of the surveyed models handled O&S costing well, and most not at all.

III. U.S. NAVY MODELS

Introduction:

Two different factors governed the reviews of models presented in this section. One, we included reviews of all documented, non-propriety models identified to date developed by or for the U.S. Navy that appear to have applicability to our effort. (The reader is reminded that the HARDMAN models are reviewed in the appendix.) Second, we also included several well-known Navy models, even if our review indicated that they would not be useful. The best known of these is FLEX. We felt it was very important at this stage of the project to document what models we had considered and why or why not we propose to use them.

One set of Navy O&S cost models that were not reviewed are those developed for and used by the (former) OP-917 cost group. These models, several of which were developed by ASC, were designed for another purpose than the focus of this study. In particular, those models were developed to provide an independent estimate of the O&S costs of weapons systems for DSARC review. These models are not structured to relate design changes to O&S costs; these models estimate costs for aircraft with design already fixed. Thus, they do not provide the requisite capability to relate design. Moreover, they estimate O&S costs only by major cost category and only for complete weapon systems.

Discussion of Models:

NAVY PROGRAM FACTORS MANUAL

Review of Model. The Navy Program Factors Manual originally was a well thought out source of operating cost information for existing ships and aircraft. As the manual states in its introduction, the Factors Manual was "derived for use in extending the dollar and manpower resources required to operate and support a single ship or aircraft." As implemented for almost 10 years the factors were computed by the Navy Resource Model (NARM) from the data used in the Five year Defense Program (FYDP) and the Program Objective Memorandum (POM). The Factors Manual has not been updated since 14 November 1980.

The Factors Manual includes both direct and indirect costs. The direct costs are very good, being carefully constructed over several years. The data sources and the algorithms by which the raw data is converted to cost factors are both carefully and fully documented. The data sources represent the most appropriate sources of relevant data. The algorithms are well thought out, representing sensible and defensible ways of calculating the factors. Another strength is that, when updating was done regularly, the factors were timely and consistent with the figures in official Navy PPBS documents, particularly POM and FYDP. If ships and airplanes were multiplied times the appropriate factors and summed, the total would be equal to the totals presented in the POM. This feature eliminates one of the major criticisms of VAMOSC data, which is that the factors in total do not agree with official Navy PPBS figures.

Indirect costs in the Factors Manual are less reliable particularly indirect support costs for ships and airplanes. Personnel overhead costs (training, health care, etc.) while at best only rough approximations, are better than nothing. One flaw they have is that they overlap in unknown ways with the Billet Cost Model. The Billet Cost Model takes into account training and attrition, but not personnel overhead costs, such as annual medical costs.

Overhead costs for ships and aircraft are another matter. Conceptually, these factors are not appropriate for the purposes of our project. Because these factors compute what support costs are for weapon systems given system design and maintenance policy. They are not tied to the design factors and support policies which cause these support costs to be what they are. For example, logistics costs are not tied to reliability and maintainability factors. Nor, given the aggregate level at which these factors are designed to be used, should they be or even could they be.

Applicability to O&S Cost Modeling. The potential value of the Factors Manual is that it could provides basic O&S cost data for ships and aircraft which can be used as baseline systems. That the factors are no larger current, of course, severely limits their usefulness for current costing purposes. Discussions with knowledgeable people at CNA mentions recent tests where when several five year old factors were inflated to 1985 levels, they were substantially at variance with current values for the same items. CNA has been tasked in December 1985 to revitalize and update the NARM and the Program Factors Manual but the time table for this renewal is not now known. Because the

algorithms are documented, it would be feasible to use them to construct one's own factors. While a task beyond the capability of this project it might be possible to do for specific costing exercises.

VISIBILITY AND MANAGEMENT OF OPERATING AND SUPPORT COSTS (VAMOSC)

Review of Model. VAMOSC is most accurately described as a database, rather than a model. To the maximum possible extent, VAMOSC accumulates actual return costs by weapons system, drawing on more than 20 other data systems to provide information pertaining to financial, maintenance, personnel, and supply functions carried out by the Navy. For those cases in which actual return costs cannot be identified to the individual weapon system level, allocations are made based on various considerations and parameters. VAMOSC output thus combines actual return costs with allocated figures. While VAMOSC addresses some costs often thought of as indirect O&S costs (e.g., training support), it does not address many indirect cost elements (e.g., indirect personnel support).

VAMOSC has two major divisions: VAMOSC-SHIPS and VAMOSC-AIR. VAMOSC-Ships is under the preview of the Naval Sea Systems Command, with VAMOSC-AIR being under the sponsorship of the Naval Air Systems Command. VAMOSC-SHIPS and VAMOSC-AIR both have the same parallel structure of two independent databases in each system: the Total Support System (TSS) and the Maintenance Subsystem (MS)(Air)/Maintenance Module (MM)(Ships).

To the extent that the reporting systems permit, the TSS uses a top-down approach which develops cost of ownership (i.e., O&S costs) by class and hull number in the case of ships, and by type/model/series in the case of aircraft. On the other hand, the MS/MM uses a bottom-up approach which addresses direct maintenance and material costs by individual hull or type/model/series.

VAMOSC-SHIPS and VAMOSC-AIR both report O&S costs of existing units in sufficient detail to enable the development of CERs by relating individual cost elements to design, physical, and operating parameters of ships and aircraft.

Applicability to O&S Cost Modeling. VAMOSC per se has no value as a predictive tool for estimating costs of proposed weapons systems. It readily lends itself to costing by analogy for some systems, and is a valuable source of cost data that could be used as the basis for developing cost estimating relationships (CERs) for inclusion in a predictive model.

In view of the fact that the Navy Resource Model (NARM) Cost Factors Manual has been discontinued, the VAMOSC system constitutes the most comprehensive repository of O&S cost information in the Navy for ships and aircraft. However, it has very little value for addressing the O&S costs of subsystems, such as ship sonars or aircraft radar.

LEVEL OF REPAIR MODELS (1390B)

Review of Model. The Navy has developed four models to determine the least costly way of doing organizational, intermediate and depot level maintenance. These four models have been formally documented as a Military Standard (MIL-STD-1390B). The four models which make up the Military Standard 1390B Level of Repair Manual include:

1. Naval Air Systems Command Equipments (AIR)
2. Naval Electronic Systems Command Equipments (ELEX)
3. Naval Sea Systems Command Ships Equipments (SHIPS)
4. Naval Sea Systems Command Ordnance Equipments (ORD).

While there are substantial analytical differences between each of these models, the common goal is to compute maintenance cost of an assembly as a function of at what level maintenance level (also called level of repair) the assembly is to be repaired. There are three levels of repair: local, intermediate, and depot. The general approach is a hierarchical structure beginning at the organizational level to either repair, discard, or sent to a higher level of repair if it is found to be BCM (beyond capability of repair). The routines, which can be called process models, have a series of equations which work through the process of remove, repair, or BCM. The 1390B models allocate costs to six major cost categories: inventory, support equipment, space, labor, training, and documentation. Different level of repair (LOR) alternatives are used to compute the cost in each category. The Electronics Model has three alternatives: local repair, depot repair, and discard. The Ships Equipment

Model utilizes eight different LOR alternatives, which include a variety of mixed repair postures.

The Air Systems Model is the more analytically complex of the 1390B models in that it can simultaneously consider three levels of indenture for equipments: WRA (Weapon Replaceable Assembly), SRA (Shop Replaceable Assembly), and sub-SRA. The Air Model's computes program includes a complex optimization routine which automatically chooses the least-cost mix of LOR postures for an item and all its sub-assemblies. The other models are single indenture models, which means they must be run for each of the MRU's (Minimum Replaceable Units) making up an item.

Applicability to O&S Cost Modeling. The 1390B models do provide an estimate of the maintenance manhours at all three maintenance levels and these estimates are tied directly to key RAM parameters - MTBF and MTTR. The Hardman review criticized the 1390 B models for underestimating actual repair time because they use engineering estimates of MTTR, direct hands on repair time, without considering the average time of the maintenance action, which, for example, would include packaging time and documentation. Independently of that criticism, the 1390B models are not integrated into the billet determination process. The question here is how maintenance manhours translates into fleet billets for maintenance personnel and billets into maintenance manpower costs.

The second criticisms is that the 1390B model's inputs and equations do not lend themselves to trading-off equipment design and maintenance skill levels and training requirements. Even if true, and for purposes of this survey we did not

investigate this issue, to handle such tradeoffs would make the models even more complex, raise their input requirements even further, and further delay when during the acquisition cycle these models could be used.

Both LMI and Hardman reviews found that the **earliest** the 1390B models have ever been used in the design process has been in the full-scale development phase. More often, however, they are not used until the production, or even deployment, phases of the cycle. Given their extensive input requirements, this is not surprising. The models have extensive and detailed requirements which can only be satisfied late in the acquisition cycle. The 1390B models are large and complex, and thus difficult to use. An alternative source for maintenance personnel requirements is needed; NAVMAN appears to be such a source.

TIGER

Review of Model. The TIGER computer program evaluates the reliability, readiness and availability of weapon systems at the system, subsystem and equipment levels. The program uses Monte Carlo simulation techniques to estimate various reliability, readiness and availability measures. Developed and maintained by the Reliability Branch, Systems Engineering Division, Naval Sea Systems Command, TIGER has been used primarily to analyze ships and shipboard systems. The program is, however, applicable to a range of weapon systems (from aircraft to tanks). A brief discussion of TIGER inputs, methodology, outputs and applicability to O&S cost modeling follows.

The TIGER user must input a variety of information related to the mission, configuration, reliability and maintainability of a weapon system. With respect to system mission, the user must input the system's "timeline" or describe the types (e.g., cruise, engagement, combat, etc.), number and duration (i.e., hours) of each mission phase to be simulated. The program accepts up to six phase types of 95 phases. With respect to system configuration, the user must identify the subsystems and equipments that constitute the system. The program accepts up to 31 subsystems. With respect to system reliability and maintainability, the user must input mean time between failure (MTBF) and mean time to repair (MTTR) for each subsystem for equipment. Additionally, the user must provide information related to the system's maintenance concept, including:

- System allowable downtime:
- Fraction of repairs performed onboard ship:
- Number of spares required per level of maintenance (organization, intermediate, depot) per equipment type; and
- Administrative delay time in delivery of spares.

TIGER uses Monte Carlo simulation techniques to simulate system performance over a specified period of time. The numbers used in Monte Carol simulation are derived from a special computer subprogram that provides a string of numbers uniformly distributed between zero and one. In TIGER this string of random numbers is used to generate simulated equipment time to failure (TTF) and time to repair (TTR). Based on the system configuration (i.e., subsystems and equipments), system up and down times are determined. From these, estimates of system reliability, availability and readiness are generated. The simulation is

repeated a number of times, each time drawing a new series of random number and averaging the simulation results to achieve statistical confidence.

More specifically, TIGER uses the Monte Carlo process to simulate operation of a user defined system (i.e., subsystems and equipments) through a sequence of user defined mission phases. The Monte Carlo process uses the statistical concept of the cumulative distribution function (CDF) of a random variable. In TIGER, the CDF is approximated the the exponential distribution function. The exponential distribution function is

$$F(t) = 1 - e^{-Lt}$$

where:

t = time > 0 and

L = reciprocal of MTBF or MTTR

Displayed below, this function represents the cumulative probability of n event (i.e., equipment failure or repair) occurring before time t.

1.0

F(t)

t

The X axis is the equipment TTF or TTR and the Y axis is the probability that failure or repair occurs before time t. The Monte Carlo process generates random TTFs and TTRs are drawn from exponential distributions having means equal to the MTBFs and MTTRs, respectively. The simulation is performed for sets of fifty mission trials until either the specification requirement for reliability or the required number of mission trials (up to 1000) is reached. At the end of each set, estimates are calculated and printed.

TIGER generates estimates for system reliability, availability and readiness and displays these estimates in a variety of standard and optional reports. The reliability estimate is the ration of the number of successful missions to the total number of attempted (simulated) mission. Two availability estimates are generated. Instantaneous availability is the ration of the number of missions during which the system is up at a specific time to the total number of attempted (simulated) missions. Average availability is the ratio of uptime to total calendar time of all the simulated missions. Finally, the readiness estimate is the ratio of uptime during the entire mission to total calendar time to the entire mission. Additionally, TIGER uses estimated reliability and user input MTTR to compute corrective maintenance hours.

Applicability to O&S Cost Modeling. Initially it was thought that TIGER output might prove useful in development of O&S cost estimating methodology. Our review of TIGER program documentation leads us to conclude otherwise. The types of reliability, availability and readiness measures generated by TIGER are probably not useful to cost estimating methodology development. However, on the

positive side, two of the required user inputs (MTBF and MTTR) are parameters worthy of further consideration. That is, MTBF and MTTR can be used together with annual operating time and hourly labor rate to estimate a key O&S element - unscheduled maintenance labor.

FLEX

Review of Model. FLEX, developed by Headquarters, Naval Material Command in 1974 and continuously updated/revised since then, is ADP software that provides a framework for automating life cycle cost estimating methodology. Issued with MIL-HDBK-259 (Navy) "Life Cycle Cost in Navy Acquisitions," the FLEX system enables the user to input a detailed cost element structure and cost estimating relationships (i.e., equations) for each element. FLEX is strictly an accounting model; it has no embedded estimating relationships. It is however designed to accept a variety of equation types; the user has the ability to employ any combination of the engineering, parametric and analogy estimating techniques. In conjunction with inputting cost estimating equations, the user must also specify the input variables and their associated input values.

FLEX has other characteristics worth noting. First, the system aggregates cost by year for a user defined life cycle but also (for management level decision making) aggregates cost by "cost category" and funding type. The then "cost categories" are: contracted research, management, testing, prime equipment, training, supply support, technical data, support equipment, operation and

maintenance. The six funding types are: research and development, procurement, construction, operation and maintenance, military personnel and others. Second, FLEX has an extensive time value of money capability that allows multiple discount and inflation adjustments as well as other user defined adjustment options including translation to foreign currencies. Finally, FLEX operates on a variety of mainframe and mini computers. Micro computer compatibility requires minor modification.

The first paragraph above discusses using FLEX to automate LCC **estimating** models. However, FLEX's most well known and best documented application is an LCC **accounting** model. The estimating vs. accounting distinction is an important one. Estimating models are necessarily analytical in nature whereas accounting models simply perform arithmetic operations on input values estimated outside the model. In January 1977, the Naval Weapons Engineering Support Activity (NWSEA) developed a FLEX based accounting model called the Naval Material Command Life Cycle Cost Guide for Equipment Analysis (hereafter referred to as the Equipment Model). The Equipment Model uses the FLEX system to estimate the life cycle cost of Navy equipment. The model comprises 61 accounting type equations (e.g., annual crew pay = number of crew multiplied by annual pay) that relate to an extensive cost element structure that accounts for all costs incurred during the three life cycle phases - R&D, investment and operating and support. The 61 equations, half of which relate to O&S cost elements, require 104 inputs.

In November 1977, NWSEA developed an enhanced version of the Equipment model called the Naval Material Command Cost Guide for Major Weapon Systems (hereafter

called Major Weapon Systems Model). The Major Weapon Systems Model incorporates several changes to the cost element structure employed in the Equipment Model. Otherwise, the two models are identical.

Applicability to O&S Cost Modeling. Because it is no estimating algorithms incorporated, FLEX has no direct applicability to our cost estimating project. Its value as a software package could be of great use on specific costing exercises or as part of a LCC model development which utilizes estimation relationships developed elsewhere or as part of this project.

COMPREHENSIVE AIRCRAFT SUPPORT EFFECTIVENESS EVALUATION MODEL (CASEE)

Review of Model. CASEE is a Monte-Carlo simulation model that estimates the operational system and subsystem capability of carrier-based conventional takeoff and landing (CTOL) and vertical takeoff and landing (VTOL) aircraft systems. CASEE estimates maintenance activities at the organizational and intermediate levels of a conventional carrier using a task network simulation approach. CASEE outputs are operational readiness parameters including sorties flown per sorties scheduled, maintenance manhours per flight hour, number of in-flight aborts, maintenance manhours by skill type, and aircraft turnaround time. It relates these output variables to subsystem/subsystem reliability and maintainability. CASEE is programmed in the Norden General Purpose Simulation System (NGPSS) language. It was used extensivly by the F-18 program manager to establish the relationship between F-18 design and system readiness, and used

elsewhere in the Navy to some extent as a design and program logistics tradeoff tool. According to NAVAIR, the model is "relatively convenient to input and run."

CASEE inputs are divided into the following categories: mission generation (including number of launches per day, mission duration, and time between launches); prelaunch activity (including time to respot aircraft and time to perform ground crew preflight); flying of mission (including failure probabilities for systems and subsystems); postflight activities (including estimated time to repair faults); unscheduled maintenance (including time to remove/install WRA's, misdiagnosis probabilities); spares availability (including cannibalization criteria); and intermediate maintenance (including work center requirements, beyond capability of maintenance probabilities, and elapsed time).

Applicability to O&S Cost Modeling. CASEE appears to be of the same family of simulation models as TIGER. The same remarks thus prevail. In particular, CASEE does not estimate costs directly, nor do it outputs lend themselves to doing so.

NAVMAN: A MODEL FOR ESTIMATING NAVY MAINTENANCE PERSONNEL REQUIREMENTS

Review of Model. NAVMAN estimates below-depot level maintenance personnel requirements for new Navy aircraft systems. The model also estimates changes in

these personnel requirements resulting from changes in key design and policy parameters need or flying hour programs, system reliability, maintainability and squadron organization. NAVMAN was designed to be an analytic tool for estimating personnel requirements early in the acquisition process using simple, readily available data as input. It appears to provide procedures not available elsewhere of estimaing maintenance personnel requirements before detailed information about subsystem reliability and maintainability characteristics and other system peculiar personnel driving factors are available.

NAVMAN's developers incorporated into a single framework the diverse methods and factors then used by the Navy to estimate below depot level maintenance personnel requirements. Its goal was, by building upon then current Navy methods, to provide "a reliable approximation of what the detailed Navy methods will eventually generate as requirements." In particular NAVMAN was based upon Squadron Manpower Requirements determination Methodology for organizational level maintenance and the ACM models for intermediate-level maintenance of NAVMMACLANT.

Input requirements of NAVMAN include (1) operations information for both sea and shore environments (sortie rate, sortie length, and flying days per week); (2) organizational features (squadron size, number of squadrons, aircraft type, and number of work shifts); and (3) maintenance characteristics (maintenance manhours per flying hour, or per sortie, or mean time between failure and mean time to repair). NAVMAN does not include any consideration of depot maintenance requirements. The model uses intermediate-level maintenance

manhours per week (an input) and the number of aircraft per squadron to calculate a squadron's total intermediate TAD workload. This total is spread to the five production divisions (Power Plants, Airframes, Avionics, Arament, and Aviators Equipment) based on historical factors stored in the model. To these are added support equipment maintenance and administrative support hours, based on historical factors. Dividing by personnel availability and converting to integer requirements gives the TAD requirements for each division.

Applicability to O&S Cost Modeling. NAVMAN's basic approach is ideally suited for the cost model we are developing, particularly its goal of providing "reliable approximations" of what detailed Navy methods will eventually generate as requirements. NAVMAN is not a cost model. However, its outputs can easily yield costs by multiplying the number of personnel, as determined by NAVMAN, times personnel billet costs, obtained from Billet Cost Model.)

The need is to update the NAVMAN's equations data bases and more importantly integrate its personnel requirements determination procedures into current Navy processes. In this regard, formal implementation of HARDMAN should facilitate the process of establishing what these processes are.

NAVMAN's use of statistical equations means that periodic updating is required. Updating, per se, is not the problem, it is merely a matter of deciding how often to update. A more serious drawback of statistical based equations is that the equations can not be used for systems differing greatly in design or maintenance philosophy from existing aircraft. The analytical issue is what

alternative methods exist that can be used during the early stages of the acquisition cycle when detailed information is simply not available.

IV. OTHER MODELS

Introduction:

In reviewing models developed for the other services, we adopted the opposite tack fr .u our review of Navy models. We reviewed only those models that appeared to have application to our work. (Our initial screen was helped substantially by the RAND and LMI reviews referenced in the bibliography.) It is clear that the Air Force has devoted more resources to model development than the Navy (over a longer period of time), that Air Force models are well documented (frequently in official Air Force publications and in all cases formal reports), and that many of these models are in use and have been in use for many years. It was therefore relatively easy to find references to and documentation on these Air Force models.

Air Force models and those developed by RAND for the Air Force were carefully considered. Preliminary reviews indicated that several well known Air Force models either were not appropriate or were redundant. These include LCOM, MOD-METRIC and LSC. LCOM has been called the "dominant" aircraft operations model in the Air Force. Unfortunately, LCOM requires substantial data input. One estimate is that it takes "at least" four to six months to develop the required data base for one run. Another estimate is 16 man months. Such data requirements preclude its use for this project. Apparently, the Air Force uses the model for determining maintenance personnel requirements for existing aircraft when LCOM's detailed inputs are available.

MOD-METRIC is another well known and widely used Air Force model. MOD-METRIC is an analytic model designed to estimate stock levels of spare parts to achieve desired supply system's performance levels. Such models are called spare allocation models. MOD-METRIC is only one of (at least) three spare allocation models used in the Air Force. The Navy's A_O model is designed to do the same purpose for the Navy.

The Logistic Support Cost Model (LSC) estimates logistic support costs as a function of alternative aircraft designs. RAND's review stated that LSC is "probably the most widely used (Air Force) model for generating O&S cost estimates during aircraft design." LSC uses 10 equations, some statistically based; each designed to estimate one aspect of logistic support. The RAND review suggests that the quality of the methodologies varies substantially but that some appear quite good. The equations work at the aircraft component. Although the specific equations and their values would not apply directly to the Navy, the LSC approach appears worthy of further investigation. However, the NAVMAN model reviewed above uses the same analytic approach, (i.e. equations which utilize data readily available doing the design phase), and needs to be investigated first.

Three Air Force models are reviewed here. One is a model developed by RAND which seemed particularly appropriate called MACO. MACO is reviewed in the appendix. A more recent Air Force model designed for avionics O&S costing but with apparent capability for wider applicability is STEP. Another Air Force model is the Modular Life Cycle Cost Model, an Air Force model apparently designed for use early in the acquisition cycle.

Discussion of Models:

STANDARDIZATION EVALUATION PROGRAM (STEP)

Review of Model. STEP3 (Standardization Evaluation Program, Version 3) is an analytic "bottom-up" cost estimation model useful for determining Life-Cycle Costs (LCC) of avionics and for determining cost savings from use of common avionics across aircraft. Costs are primarily Operations and Support (O&S) costs. STEP was developed for the Air Force Avionics Laboratory; it is well documented and implemented on a variety of Air Force computers. The latest documentation is the STEP3 User's Guide dated September 1984, prepared by Systems and Applied Sciences Corporation of Dayton, Ohio.

The STEP3 model is a "bottom-up" cost estimation model, using detailed costs and factors to produce an overall cost estimation. Its coverage of support investment costs is quite good. It is useful for evaluating cost savings from use of common avionics across different aircraft. The analyst may request annual and summary detailed cost breakouts by each avionics item, by aircraft program, as well as by total LCC. In addition, STEP3 can output reports of avionics spares requirements, support equipment requirements, and avionics reliability rates.

STEP3 is an interactive computer program. The analyst may make several iterations to achieve a satisfactory result. Thus, the analyst may modify data input on each iteration in order to gain "insight" into the expected results. STEP3 will perform such a "sensitivity analysis" for LRU and SRU costs, and for

their failure rates. Cost savings are computed by **two submodels:** a unit-cost/production-quantity learning curve, and a failure/operating-time learning curve, the **Duane reliability growth** model.

Applicability to O&S Cost Modeling. While STEP is an LCC model, and lives up to this criteria by its coverage support investment, particularly support equipment, it does deal directly with O&S costs for avionics. Its use of the Duane reliability growth model is an interesting feature and one primarily useful for avionics. However, STEP allows the user to specify which SRUs make up an LRUs. This feature is an interesting one and appears to reflect the actual design process. Components are not usually all new or off the shelf; the design process STEP allows the cost analyst to specify the LRU he is interested in.

Several other features of STEP are worthy of incorporation. One is that many of its required cost inputs are standard factors available from AFR 173-10, the Air Force's equivalent to the Navy's Program Factors Manual. Many models have been developed with the availability of their data input being a secondary consideration. Another feature is that the model is structured specially to help the cost analyst but whose equations capture the system design process for avionics, particularly its use of LRUs and SRUs.

MODULAR LIFE CYCLE COST MODEL

Review of Model. The Modular Life Cycle Cost Model (MLCCM) is a computerized methodology for conducting design/performance/life cycle cost

trade studies at the subsystem level during the conceptual and preliminary design stages of an advanced technology aircraft development program. Developed by Grumman Aerospace Corporation and Lockheed-Georgia Company for the Air Force Flight Dynamics Lab, Wright Patterson Air Force Base, MLCCM is designed to provide design engineers with the capability to predict and relate aircrat system life cycle cost to design parameters that can be identified and controlled early in the design phase. More specifically, the model's LCC estimating relationships are driven by user inputs that include design and performance parameters obtained either from available aircraft sizing models or from preliminary/conceptual design data.

MLCCM is an evolving model. The development process was initiated in 1975 and model improvement continues today. The most recent, available (through Defense Technical Information Center) MLCCM documentation dates to January 1980.[1] Among other things, this report defines the life cycle cost element structure and describes the cost estimating relationships (CERs) formulated for each cost element. Parametric in nature and developed using the step-wise regression technique, the CERs relate cost to two or more design/performance parameters. Two sets of CERs were developed - one for fighter/attack aircraft, the other for cargo/tanker/transport aircraft. The report describes the CERs cost driving parameters and their range of sample values, and offers rationale for selection of these parameters.

Applicability to O&S Cost Modeling. The devlelopers of MLCCM made a concerted effort to model operating and support costs thoroughly. CERs were developed for the following mjor O&S cost categories:

- o Base Level Maintenance
- o Replenishment Spares
- o Depot Component Repair
- o Base Level Operations
- o Base Level Training
- o Depot Airframe

  (including Programmed Depot Maintenance)
- o Non-Design Related O&S Costs
- o Other Maintenance
- o POL

The first three cost categories are estimated for each aircraft subsystem. The remaining cost categories are estimated at the system level. The O&S CERs generate estimates in dollars per flight hours, dollars per aircraft per year or dollars per year.

According to a recent telephone conversation with the MLCCM Program Managr, the next iteration of MLCCM improvements will be available to the public early January 1986.[2] He indicated that the O&S CERs included in the latest documentation represent significant improvements to the present CERs.

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[1] Grumman Aerospace Corporation, **Modular Life Cycle Cost Model for Advanced Aircraft Systems Phas III: Volume 1, Revision 1 - Cost Methodology Development and Application**, January 1980, AFFDL-TR-78-40, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio.

[2] 10 December 1985 telephone conversation with LT Nathan Martens (USAF), Flight Dynamics Laboratory, Wright-Patterson Air Force Base.

APPENDIX

AN EVALUATION OF MACO AND HARDMAN COST MODELS

Introduction:

This appendix documents our evaluation of two candidate cost models: the Model for Estimating Aircraft Cost of Ownership (MACO), developed by RAND (R-2601-AF, August 1981) and a model developed as part of the HARDMAN project.

Framework for Evaluation of Models:

The overiding requirement for selecting a candidate O&S cost models is that it be effective early in the design process when the majority of Life Cycle Costs are determined. Additionally, the cost model inputs must be obtainable from current data bases, and must be compatible with the established organizational responsibilities within the Navy SYSCOMs. Current practice, for instance, fractionates cost analysis responsibility among designers, logisticians and cost analysis groups. An effective cost analysis system must provide cost communication among system design groups, logistics specialists, cost analysis specialists and Program Management. Because manpower costs are the largest single element in LCC, the model must cover all manpower, personnel, and training (MPT) costs and estimate them correctly. The model must also address system design, and integrated logistics support (ILS), and tie these together in such a way that the Program Manager can make timely and intelligent trade-off decisions.

This means that the O&S cost model must use and assist the PM in integrating the same data used in developing the Logistics Support Analysis (LSA), TPM, ILSP, and Work Breakdown Structure (WBS).

Specific criteria that were used to evaluate these cost models are:

- o Can be used effectively early in the Weapons Acquisition cycle before O&S costs are locked in, and structured so that inputs can be refined as the program matures.
- o Identifies implicit or explicit trade-offs between cost and performance or capability, and between acquisition cost and O&S costs.
- o Uses cost elements that are internally consistent and responsive to the CAIG guidelines, and are defined in terms of Navy programming, budgeting and accounting categories.
- o Compatible with existing Navy databases.
- o Outputs in terms of absolute costs in order to be able to compare and trade off O&S and acquisition costs.
- o Uses algorithms for resource categories that are responsive to a wide range of system characteristics, support concept and operations concept cost driver variables.

Evaluation of Models:

Our review concentrated on the following documents:

- o "An Appraisal of Models Used in LCC Estimation for USAF Aircraft Systems", RAND R-2287-AF, October 1978

- "A New Approach to Modeling the Cost of Ownership for Aircraft Systems," RAND R-2601-AF, August 1981
- The **HARDMAN** series authored by T.M. Neches and Robert Butler, which spanned the period October 1978 to September 1983.

Our initial review shows that an acceptable base exists within the Air Force and Navy for constructing a model which meets the criteria cited in the previous section. In particular, the models addressed by the second and third sources are oriented specifically toward effectiveness early in the design process. The HARDMAN models go further in providing continuity of methodology throughout the Weapons System Acquisition Process, and are further along in their development as operational tools. However, MACO represents a fully thought out approach to an aircraft cost model.

RAND publication R-2287-AF is briefly summarized to lay a foundation for comparing the MACO model treated in RAND publication R-2601-AF with the HARDMAN models. Our primary concentration is on the MACO and the **HARDMAN Life Cycle Cost System: Avionics Equipments**[1] Models. These models are very close in terms of purpose and commodity class.

RAND Evaluation of Eight LCC Models (R-2287-AF):

RAND publication R-2287-AF analyzed 8 LCC models used widely by the USAF in 1978. At least four of these (LSC, LCOM, DAPCA, and PRICE) are still used extensively in the DOD. Moreover, the AFR 173-10 models are still used in the Air

Force. The models evaluated were:

- o AFR 173-10 models (BACE and CACE)
- o Logistics Support Cost Model (LSC)
- o Logistics Composite Model (LCOM)
- o MOD-METRIC
- o AFM 26-3 Manpower Standards
- o AFLC Depot Maintenance Cost Equations
- o DAPCA (Development and Production Costs of AIC)
- o PRICE (RCA model for avionics development and procurement costs)

These models were evaluated within the framework of a cost driving factor/cost element matrix shown as Figure 1. The columns of the matrix are CAIG cost elements. The rows are cost driver factors. Shaded retangles indicate that no (or weak) causal relationship is expected between the cost driver and cost element. We use this same framework for evaluating the coverage of the two candidate models and then relate coverage to the criteria stated above.

The models were subjectively evaluated by the authors of R-2287-AF according to the coverage of the model for each element of the matrix. Good coverage indicates that a models estimating method closely follows the actual relationship between cost and driving factors. A fair coverage indicates that the cost driving relationship was only partially reflected in the estimating technique. For example, the investment cost of support equipment should be related to system reliability and maintainability characteristics, but most

models simply relate support equipment cost to flyaway investment cost. Poor coverage indicates the model dealt with only a minor portion of the expected cost effect, treated the relationship in a possibly misleading way, or had an unknown relationship to the content of the cost element. No coverage by model indicates that the element was covered by a through put. A blank (cost element not covered by model) indicates that none of the models addressed that element.

Figure 2 shows the evaluation of the eight models by the authors of R-2287-AF. Only five elements were marked as good coverage by any model and all models were rated as generally unacceptable according to the authors' evaluation criteria.

MODEL FOR ESTIMATING AIRCRAFT COST OF OWNERSHIP (MACO)

RAND publication R-2601-AF is an attempt to develop a new and improved model by combining and modifying three of those analyzed above (BACE/CACE and LSC). The stated intent was to combine the depth in terms of responsiveness to aircraft system design characteristics, visibility and subsystem demands for resources, and respresentation of base level and depot level logistics processes of the LSC model with the breadth of BACE/CACE. However, MACO was never programmed for any computer and was not tested. Additionally, the algorithms and parameter estimates, in many cases, are specific to USAF fighter type aircraft and USAF maintenance/support policy. Consequently, nearly all of the cost equation parameters would have to be re-estimated using Navy data. Figure 3 shows the

coverage of MACO, using the same cost driving factor/cost element matrix used by the authors of R-2287-AF for evaluating the eight models treated in their study.

In constructing Figure 3, no attempt was made to distinguish between good and fair coverage. Coverage of the matrix elements was determined by examining the equations which were added to the LSC and BACE/CACE models, along with the authors' statements concerning deletions. It was assumed that fair or good coverage shown in Figure 2 remained at least as good, except in those cases where coverage was deleted.

Six cost elements were omitted from MACO; four of these are support investment items and two are O&S items. Omitted elements and the authors' reasons are:

- **Training Equipment & Services and Documentation Costs.** These depend to a great extent on factors peculiar to the prime contractor. Estimation of these costs can be deferred until the program is far enough advanced that the prime contractor can provide his estimates of these costs.
- **Facility Costs.** These are highly program specific.
- **War Reserve Material.** The cost of WRM spares is estimated in a way which differs significantly from the process used for peacetime requirements. WRM ordnance is not significantly sensitive to system characteristics to warrant attention.
- **Depot Supply and Second Destination Transportation.** These costs are indirectly attributable to individual weapon systems.

These omissions of the O&S items of depot supply and second destination transportation will be considered further as part of our analysis of the HARDMAN model.

In addition to the above omissions, the authors state that the handling of support equipment acquisition cost is not adequate. Common support equipment is estimated as a function of flyaway costs. Peculiar support equipment is estimated as the product of quantities and prices which are not available until later in the acquisition cycle.

A major problem with MACO as a foundation for a Navy aircraft O&S cost model is that many of the estimating relationships are tailored to USAF specific data sources, and basing and deployment policy. This shows up particularly with respect to the Basing and Deployment Concept and Mission type and Profile cost drivers for all covered cost elements. Below Depot and Depot Maintenance cost elements are generally USAF specific, primarily reflecting Air Force policy and databases. Below Depot Maintenance manpower costs depend heavily on data and estimating relationships developed as part of the NAVMAN program. This study, conducted by RAND for PA&E, was discontinued in 1980. The logic of the NAVMAN estimating equations are carefully documented and are available for our use. Depot Maintenance manpower costs are derived from the Air Force Depot Maintenance Cost Accounting/Production Report System (H036B).

Personnel Training and Support & Sustaining Investment cost elements, which are covered at all, are generally treated inadequately or use through put data.

This appears to be a particularly serious deficiency in the case of Individual Training, Replacement Spares and Modifications. The treatment of Replacement GSE is related to the handling of Support Equipment Investment.

In order to put the above observations in perspective, we next present the coverage of the HARDMAN models. This will facilitate our evaluation in that the two can be more easily compared and contrasted. Overlaps and gaps in coverage, as well as inherent strengths and weaknesses can then by evaluated in the context of our evaluation criteria.

HARDMAN LIFE CYCLE COST MODELS

The HARDMAN LCC models, show more promise as a starting point for our purposes, possibly in conjunction with MACO. These are primarily electronics/avionics models with applications to both ships and aircraft. The models have been programmed for both the H-P programmable calculator and a 64K microprocessor. Although the evaluation is specific to one model currently used by the Navy, we have examined the documentation for three predecessor models and a proprietary model currently marketed by the same authors.

The HARDMAN models were consturcted to concentrate heavily on life cycle costs trade-off analysis during the design phase.

1. The need for guidelines is real only during the design phases of

the WSAP, when the maximum number of actors are making decisions which influence cost and the decisions made have the maximum impact on the eventual total life cycle cost of the system. Decisions made during the very earliest and later stages of the WSAP are generally made by a small number of specialists. In the later stages, these specialists are already equipped with relatively good tools. In addition, the potential for cost savings during the later phases of the WSAP is small compared to the possibilities available during the design phases.

2. The problems which must be overcome to conduct cost trade-offs are such that "the system is the solution." That is, a properly constructed cost analysis model system will itself solve most of the methodological problems of trade-off analysis.

This makes sense in the context of this study and supports our observation above; that an aggregated "bottom up" model which can be refined and made more accurate as the program matures is superior to one using trends and analogy without due regard for causal relationships.

The HARDMAN models are linked and graded, which means that they are intended to satisfy our first criteria. The Avionics model, which we are considering, consists of seven linked programs: a Top-Down Model (TDM); a Lowest Removable Assembly Model (LRAM); a Systems Aggregation Model (SAM); a Data Input Utility program (DATIN); a Military Operated Depot Model (MOD); a Manpower, Personnel and Training report for the Top-Down Model (MPT-TDM); and a Manpower, Personnel and Training report for the System Aggregation Model (MPT-SAM).

Each of the models is appropriate to a different design phase and aggregation level. The TDM is used early during concept formulation, LRAM is used during design, and SAM estimates equipment or assembly costs by aggregating the output of LRAM. DATIN is a data inpu utility, and MOD determines average cost of assemblies at a NARF. MPT-TDM and MPT-SAM produce Manpower, Personnel and Training (MPT) requirements associated with the given Top-Down and Bottom-Up estimates, respectively.

The model was developed from earlier HARDMAN cost models and is programmed for an H-P programmable calculator. The earlier cost models also included a less aggregated model programmed for a 64K microcomputer. A version of each model is incorporated in a proprietary package currently being marketed for installation on a PC-XT computer.

Figure 4 shows the coverage of the HARDMAN avionics model for comparison with MACO. In general, the HARDMAN model has greater breadth of coverage across cost elements, but not across cost drivers. However, the areas of omission of the HARDMAN model are perhaps simpler to overcome. These are generally related to force size, basing and deployment and mission type and profile. Additionally, basing and deployment (were covered) is Navy specific. This is of particular importance since basing is broken down into ship and shore. This is a particularly USAF specific area of MACO coverage, and one which would have to be modified for Navy use.

Several aspects of the Hardman models need modification because of their specific focus. Force size is not treated comprehensively by HARDMAN. As a result, our fifth criterion of absolute costs is not entirely met. However, the HARDMAN model does provide absolute costs as far as it goes. Using either model would require building a factors database and/or respecifying some algorithms for many of the elements related to crew size/composition, force size, basing and mission type. In the case of the HARDMAN, many of the mission type elements could be covered merely by changes to specific equipments lists.

In terms of cost elements, HARDMAN does have better coverage than MACO. In fact, the HARDMAN coverage is more than the scope of our project because system investment is treated. This was omitted from MACO because the DAPCA and PRICE models provide fair coverage of this element and MACO thus concentrated on support investment and O&S costs. HARDMAN uses learning curve data for all investment calculations and appears to be adequate in this area.

HARDMAN covers Support Equipment costs. However, assumptions about price must still be made, as is the case with MACO. Quantities are related to specific equipments rather than flyaway costs, as for MACO.

Training, Equipment and Services are covered by HARDMAN. However, the observation of the MACO authors that such costs are highly dependent on factors peculiar to the prime contractor may be valid. This also applies to documentation costs. This is an area which merits further analysis.

The treatment of spares and spare engines is about equal in the two models. Spare engines are handled as assemblies built up from SRAs in HARDMAN. These cost elements are strong points of both models.

Facilities and WRM are not handled by either model. The reasons given by the MACO authors for omitting them appear to be justified. These costs can be calculated outside either model.

Deployed Unit Operations cost elements are not covered by HARDMAN. However, these are service specific cost elements and are fairly easily obtainable from standard Navy databases. Aircrews, command staff, security and other deployed manpower are inputs to the HARDMAN Information System (HIS) and are available early in the acquisition cycle. These can also be estimated using the Baseline Comparable System during the Concept Formulation phase. POL requirements can be estimated using parametric methods and readily available data. Miscellaneous O&M requires further research. This is treated in part by HARDMAN. However, neither model provides adequate coverage of miscellaneous O&M nor Installation Support.

HARDMAN provides the best coverage of Depot Maintenance, and the only coverage of Depot Supply and Second Destination Transportation. Depot Supply is treated explicitly by HARDMAN. However, the scope of this review did not allow a thorough evaluation of the data available as inputs for these cost elements.

HARDMAN is also preferred for Individual Training. This is true for all areas of training. The primary purpose of the HARDMAN project is early and accurate inputs to the MPT plan. This, combined with the analytic approach of the authors and tailoring the model to design trade-off analyses, has resulted in a model well suited to the purposes of this project.

HARDMAN also provides better coverage of the Sustaining Investment cost elements. Training ordnance, which is dependent on training concept, force size and mission type, is fairly easily calculated outside the model.

Relation to Evaluation Criteria:

Overall, HARDMAN is a better starting point for purposes of this project. The model identifies trade-offs between cost and performance or capability, and between acquisition cost and O&S costs using causal relationships in most cases. Primary deficiencies are in areas for which data are generally deficient early in the acquisition cycle or are readily available within the Navy.

Both model use cost elements which are internally consistent and responsive to CAIG guidelines. HARDMAN uses Navy PPBS accounting categories and model parameters have been estimated using Navy data. Generally, the cost elements not covered by HARDMAN can be treated outside the model or modeled and combined with HARDMAN as is not exists.

Both models were initially derived with the objective of being responsive to a wide range of system characteristics, support concept and operations concept cost driver variables. However, the MACO development stopped in 1981 and HARDMAN was continued to an operational model.

Because of its common conceptual underpinning, MACO should be examined in more detail for purposes of comparing basic analytic relationships with those of HARDMAN. Development of HARDMAN, to fully exploit its analytic methodology and maturity, appears to be a low risk approach. HARDMAN has been programmed for a programmable calculatro and a less aggregated version of the model has been programmed for a microprocessor. Eventual programming of a more complete model built around these two versions should therefore represent a significant savings over starting from scratch with MACO. Additionally, HARDMAN is consistent with the HIS database. This provides the advantages of being able to establish a Baseline Comparable System with much less effort.

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[1] Chief of Naval Operations, **User's Guide to HARDMAN Life Cycle Cost System: Avionics Equipments**, HARDMAN Development Office (OP-111C), HARDMAN publication 84-07, September 1983.

[2] Thomas M. Neches and Robert A. Butler, **Guidelines for Hardware/Manpower Cost Analysis**, Office of the Chief of Naval Operations, Department of the Navy, AG-PR-A100-2, October 1978.

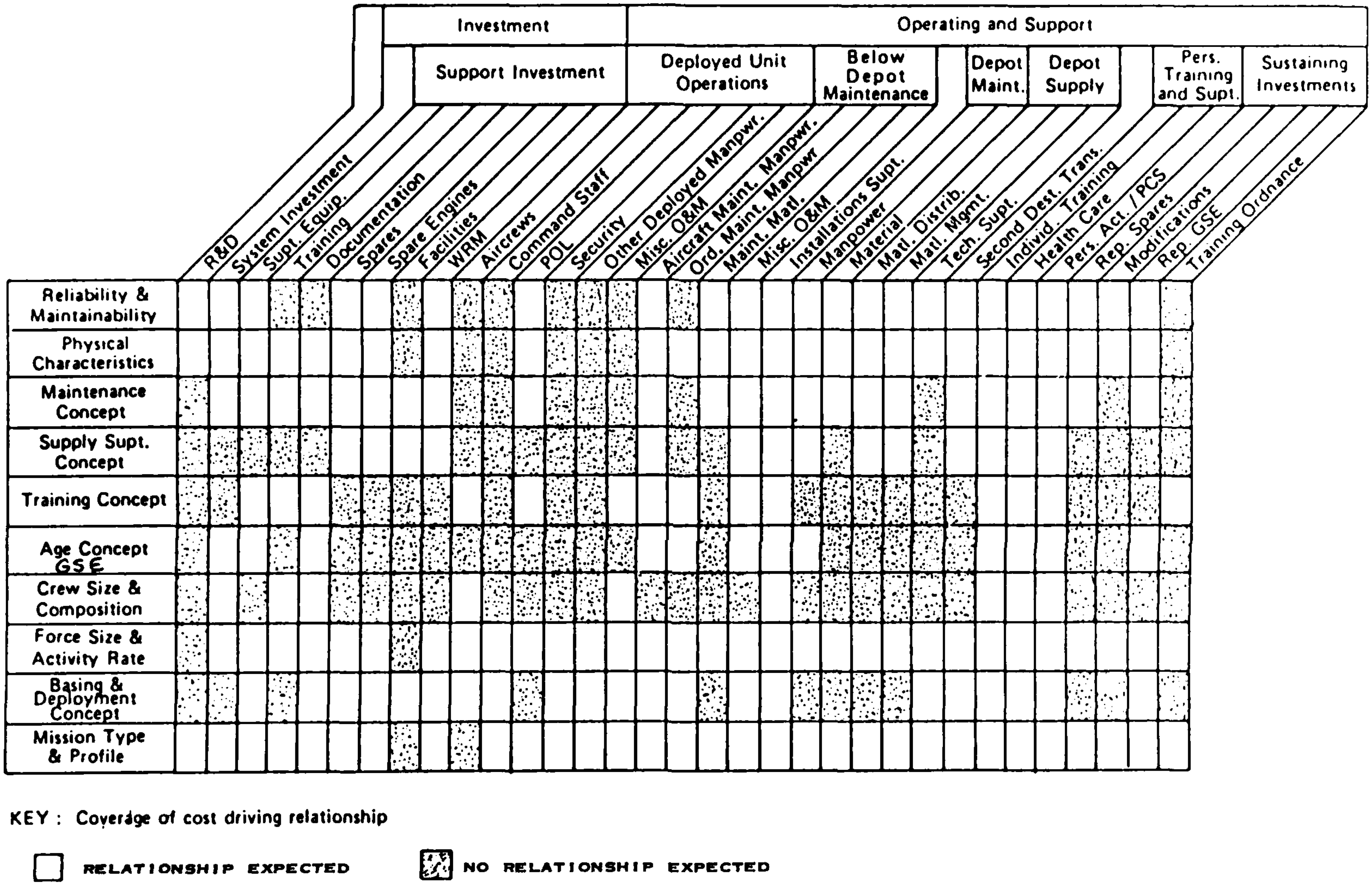
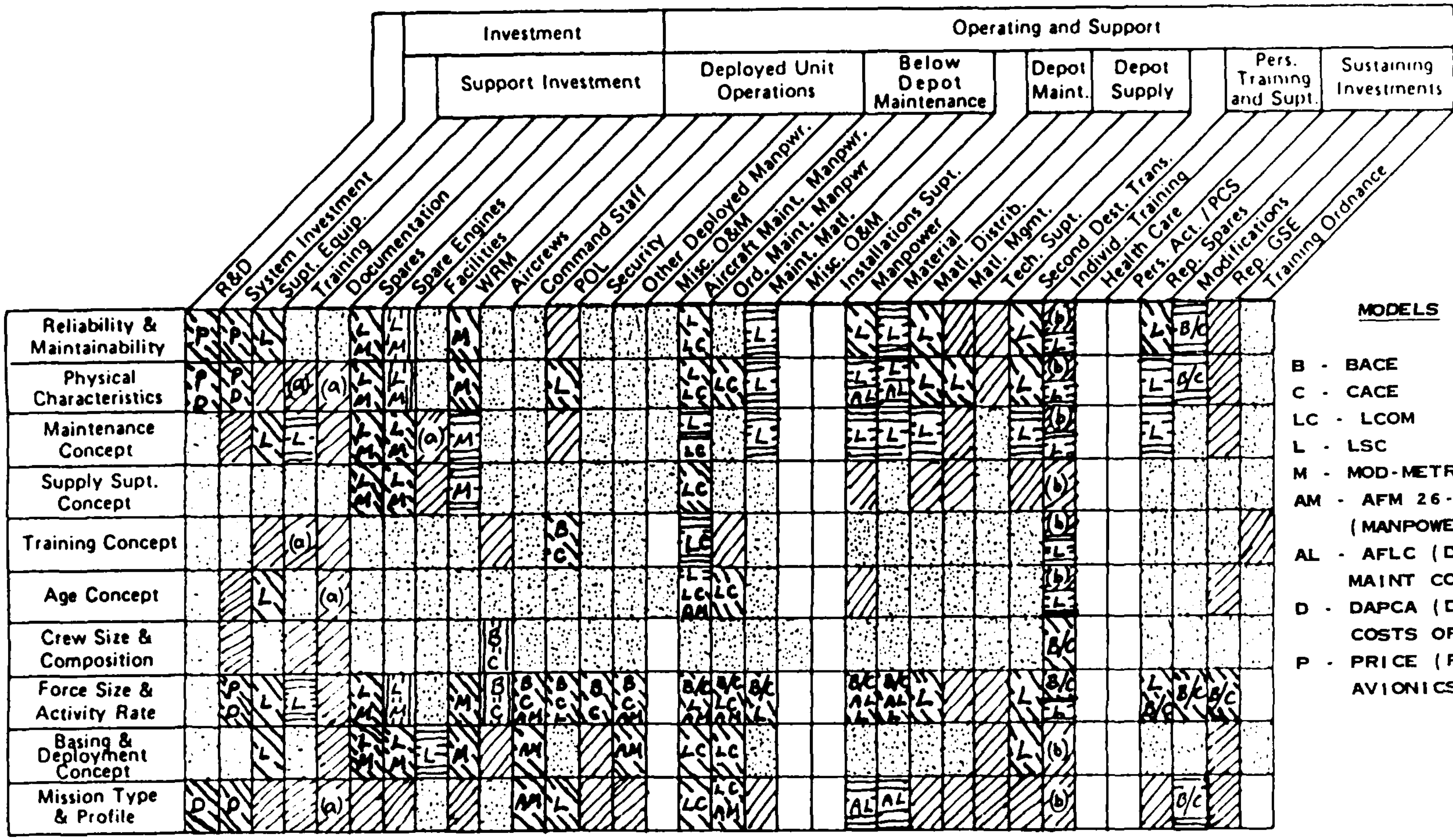


FIG. 1 - COST DRIVING FACTOR/COST ELEMENT MATRIX



MODELS

B - BACE
C - CACE
LC - LCOM
L - LSC
M - MOD-METRIC
AM - AFM 26-3 (MANPOWER STAND)
AL - AFLC (DEPOT MAINT COST EQTN)
D - DAPCA (DEV & PRC COSTS OF A/C)
P - PRICE (RCA AVIONICS MODEL)

KEY: Coverage of cost driving relationship

- GOOD COVERAGE
- FAIR COVERAGE
- POOR COVERAGE
- NO COVERAGE BY MODEL
- NO RELATIONSHIP EXPECTED
- COST ELEMENT NOT COVERED BY MODEL

(A) MAINTENANCE TRAINING EQUIPMENT COST IS THROUGHPUT FOR LSC
(B) B/C PROVIDES INDIRECT THROUGH MANPOWER WHICH IS INPUT

FIG. 2 - OVERALL COVERAGE OF THE COST MODELS

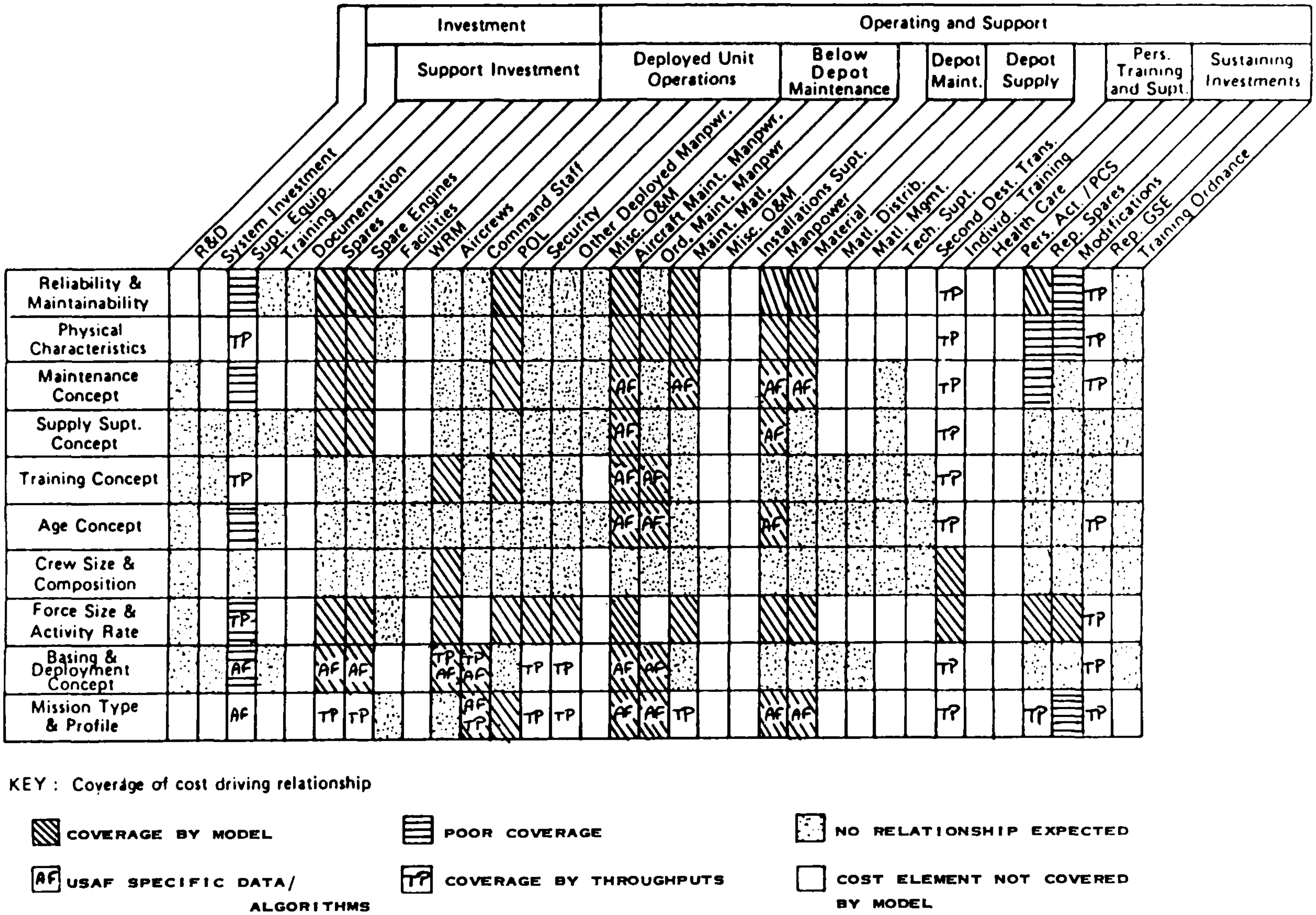


FIG. 3 - COVERAGE OF THE MACO COST MODEL

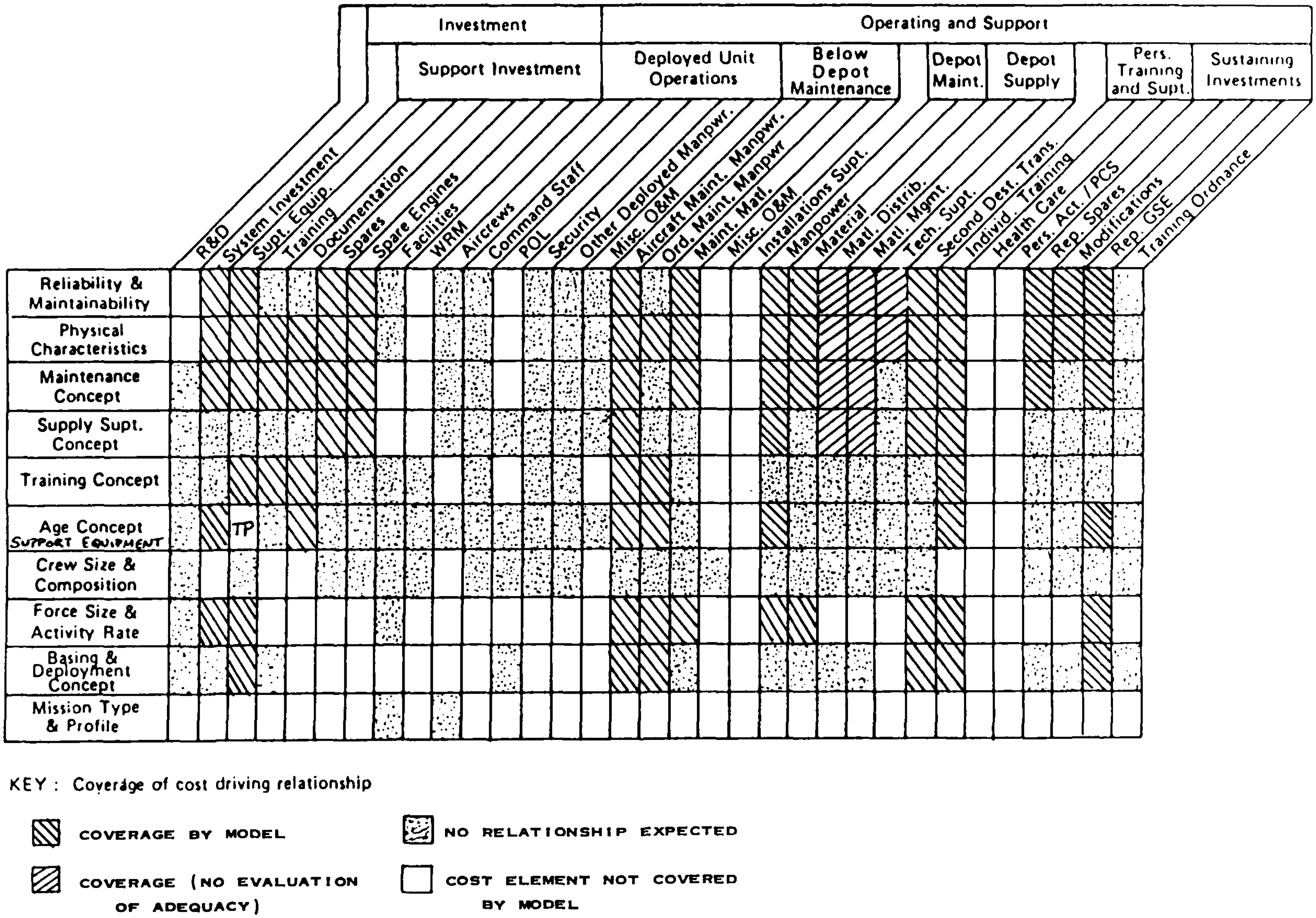


FIG. 4 - COVERAGE OF THE HARDMAN LCC AVIONICS MODEL

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